# Radar & Antenna Engineering

## Antenna Arrays

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# Antenna Arrays

The gain of a single antenna element is not sufficient for most applications. Under these circumstances, use of arrays provides the answer.

Arrays are used to **increase the gain** just like cascaded amplifiers are used to increase the gain. Arrays are also used to increase directivity and reduce beam width.

Antennas are used in both scan and unscan applications. A radiation pattern or beam can be scanned by a single antenna like a parabolic dish using a motor. Here, the entire antenna system is rotated to change the direction of the beam. When such antennas are airborne, there is a considerable amount of aerodynamic drag. Moreover, even when the antenna is on the ground, it is difficult to track the target if it is moving with a very high velocity. This is due to the limited speed of the motor which in turn limits the scan rate of the antenna. When the antenna directs its beam in a direction to catch the target, the target will be in a different direction due to its velocity being greater and it will always be out of sight.

In such situations, array antennas are more useful as it is possible to scan the beam from the arrays electronically. The electronic scanning can be with either phase control or frequency control. Here, the antenna is fixed and only the beam is rotated. The scan rate can be as high as a fraction of a microsecond with digital phase shifters.

In general, the total field produced by the antenna array at a far distance is the vector sum of the fields produced by the individual antennas of the array.

The individual element is generally called **element** of an antenna array.

The antenna array is said to **linear** if the elements of the antenna array are equally spaced along a straight line.

The linear antenna array is said to be **uniform linear array** if all the elements are fed with a current of equal magnitude with progressive uniform phase shift along the line.

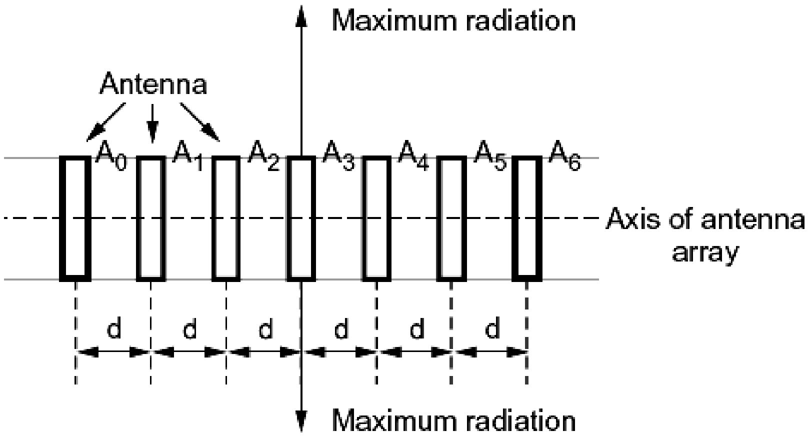
## VARIOUS FORMS OF ANTENNA ARRAY

Some of the practically used forms are as follows.

- Broadside Array
- End fire Array
- Collinear Array
- Parasitic Array

### Broadside Array

This form of the antenna array is one of the most important practical forms used in practice. The broadside array is the array of antennas in which all the elements are placed parallel to each other and the direction of maximum radiation is always perpendicular to the plane consisting elements. A typical arrangement of a broadside array is as shown below.




A broadside array consists number of identical antennas placed parallel to each other along a straight line. This straight line is perpendicular to the axis of individual antenna. It is known as axis of antenna array. Thus each element is perpendicular to the axis of antenna array.

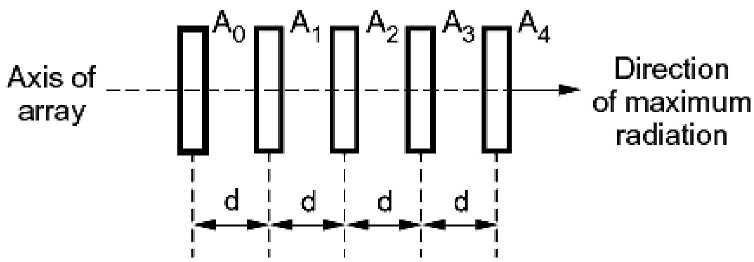
All the individual antennas are spaced equally along the axis of antenna array. The spacing between any two elements is denoted by 'd'. All the elements are fed with currents with equal magnitude and same phase.

As the maximum radiation is directed in broadside direction i.e. perpendicular to the line of axis of array, the radiation pattern for the broadside array is bidirectional.

Thus we can define broadside array as the *arrangement of antennas in which maximum radiation is in the direction perpendicular to the axis of array and plane containing the elements of array.*

## End Fire Array

The end fire array is very much similar to the broadside array from the point of view of arrangement.

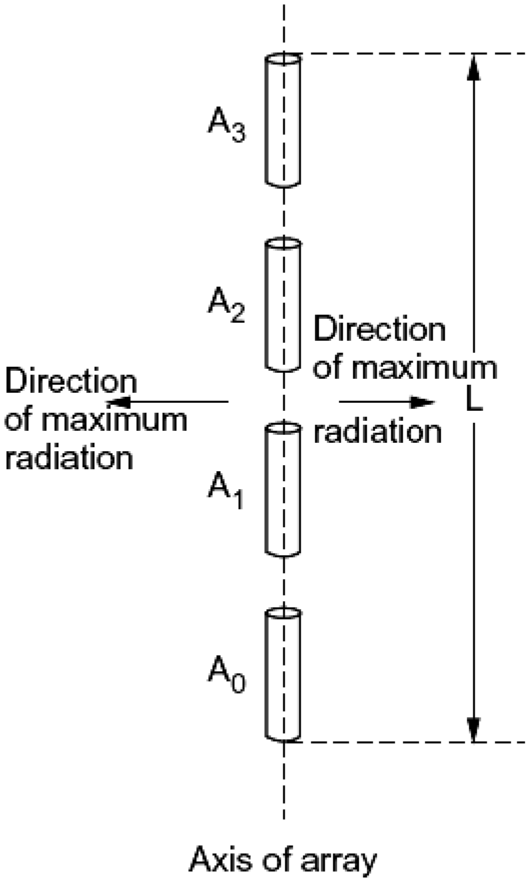



But the main **difference** is in the *direction of maximum radiation*. In broadside array, the direction of the maximum radiation is perpendicular to the axis of array; while in the end fire array, the direction of the maximum radiation is along the axis of array. Thus in the end fire array number of identical antennas are spaced equally along a line.

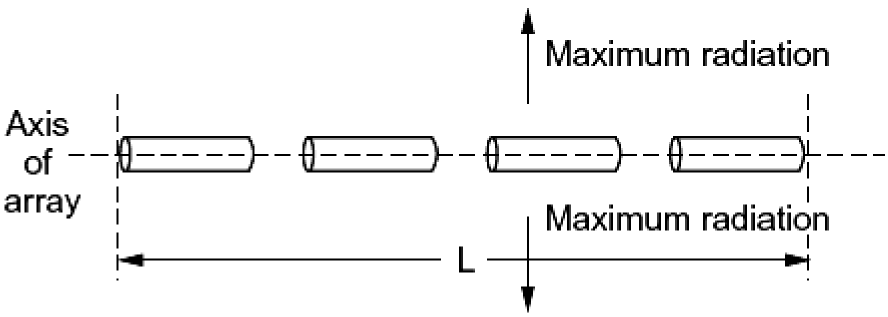
All the antennas are fed individually with currents of equal magnitudes but their phases vary progressively along the line to get entire arrangement unidirectional finally, i.e. maximum radiation along the axis of array. Thus end fire array can be defined as an array with direction of maximum radiation coincides with the direction of the axis of array to get unidirectional radiation.

## Collinear Array

As the name indicates, in the collinear array, the antennas are arranged co-axially i.e. the antennas are arranged end to end along a single line as shown in the Fig. (a) and (b).




**Vertical array**




**Horizontal array**

The individual elements in the collinear array are fed with currents equal in magnitude and phase. This condition is similar to the broadside array. In collinear array the direction of maximum radiation is perpendicular to the axis of array.

So the radiation pattern of the collinear array and the broadside array is very much similar but the radiation pattern of the collinear array has circular symmetry with main lobe perpendicular everywhere to the principle axis. Thus the collinear array is also called Omni directional array or broadcast array.

The power gain of the collinear array does not increase in proportion with number of elements.

Collinear array with more than 4-elements is not practically used as power gain is not sufficient. But practically two element collinear array is used as it allows multiband operation. It is generally known as two half waves in phase.

## Parasitic Array

In order to o overcome feeding problems of the antenna, sometimes, the elements of the array are fed through the radiation from the nearby element.

The array of antennas in which the parasitic elements get the power through electromagnetic coupling with driven element which is in proximity with the parasitic element is known as parasitic array.

The simplest form of the parasitic array consists one driven element and one parasitic element. In **multi element parasitic array**, there may be one or more driving elements and also one or more parasitic elements. So in general the multi-element parasitic array is the array with at least one driven element and one or more parasitic elements.

The common example of the parasitic array with linear half wave dipoles as elements of array is **Yagi-Uda array** or simply Yagi antenna.

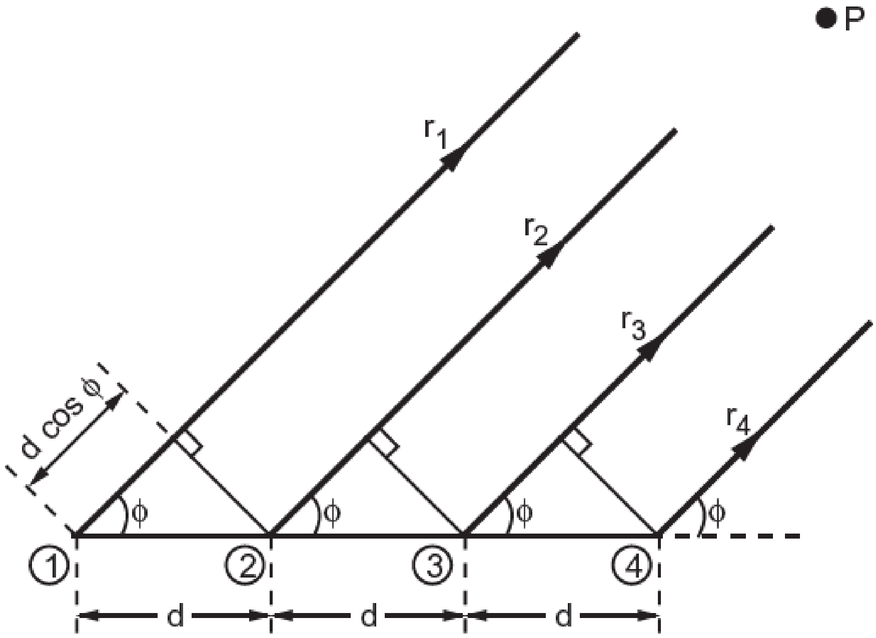
The amplitude and the phase of the current induced in the parasitic element depends on the spacing between the driven element and parasitic element. To make the radiation pattern unidirectional, the relative phases of the currents are changed by adjusting the spacing between the elements. This is called **tuning of array**.

## PATTERN MULTIPLICATION METHOD

There is a simple method of obtaining the same patterns of the arrays. This method is known as pattern multiplication method.

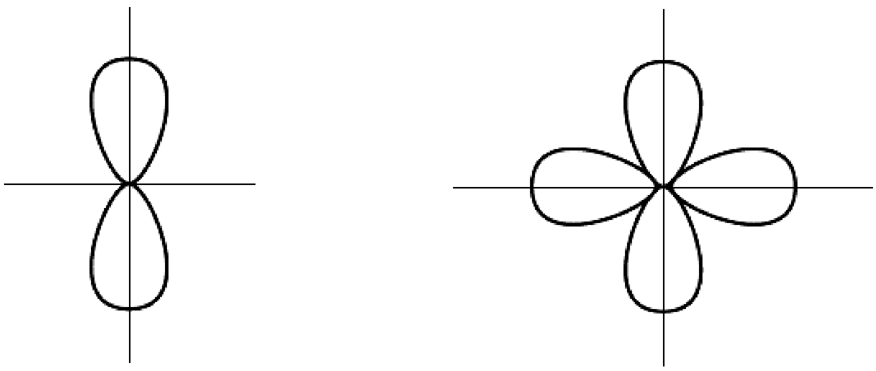
This method is a very useful in the design of arrays because it makes possible to draw the patterns of complicated arrays rapidly, almost by inspection.

To illustrate this method, consider 4 element array of equal spaced identical antennas as shown in the figure. Let the spacing between two units be d = $\lambda/2$. Also assume that all the elements are supplied with equal magnitude currents which are in phase.



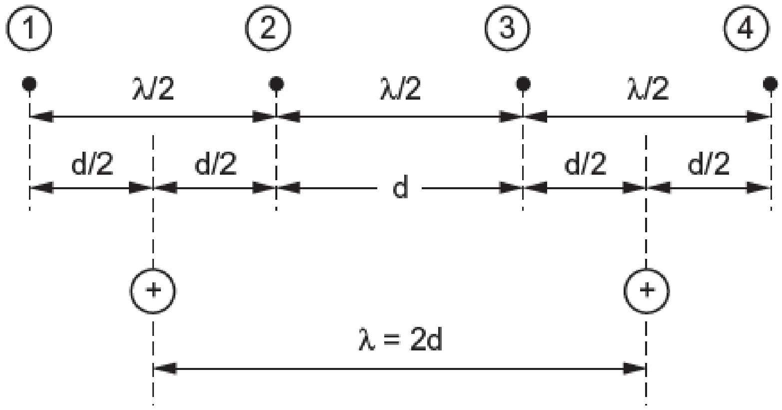

As the point P at which the resultant field has to be obtained is far away, we can assume the radiation from the antenna in the form of parallel lines.

The radiation pattern of the antennas (1) and (2) treated to be operating as a single unit is as shown in the Fig. (a). Similarly the radiation pattern of the antennas (3) and (4), spaced $\lambda/2$ distance apart and fed with equal current in phase, treated to be operated as single unit is again as shown in the Fig. (b).



**(a)** **(b)**

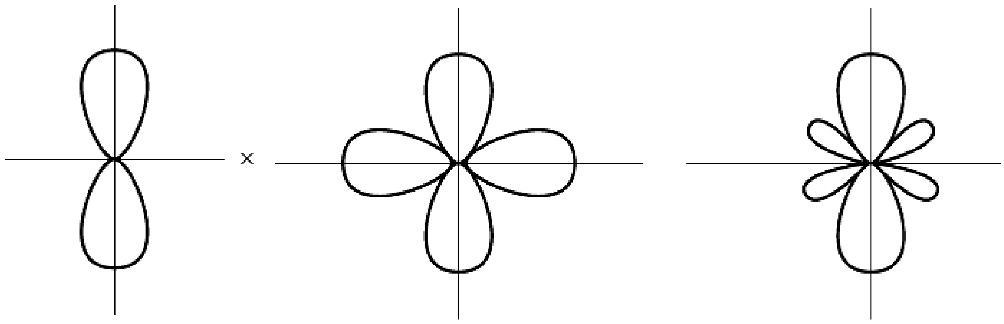
Now instead of considering two separate elements (1) and (2), we can replace it by a single antenna located at a point midway between them as shown in the Fig. (c).




Similarly replacing antennas (3) and (4) by single antenna having same pattern as shown in the Fig. (c).

Now both the antennas have bidirectional pattern i.e. figure eight pattern spaced distance λ apart from each other, fed with equal currents in phase is as shown in the Fig. (b).

Now the resultant radiation pattern of four element array can be obtained as the multiplication of pattern as shown in the Fig. (d).




Note that this multiplication is polar graphical multiplication for different values of $\phi$.

**Advantage of method of multiplication.**

It helps to sketch the radiation pattern of array antennas rapidly from the simple product of element pattern and array pattern.

**Disadvantage**

The principle is applicable only for arrays containing identical elements.

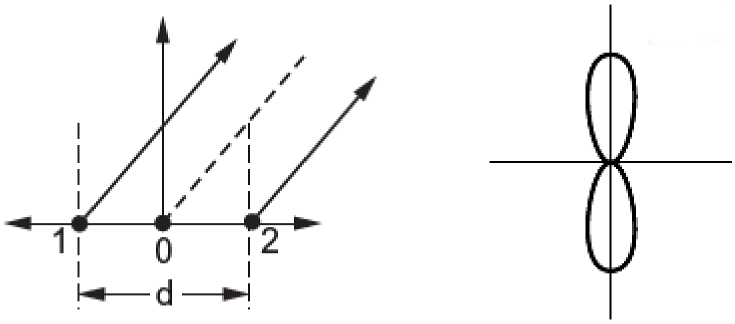
## BINOMIAL ARRAY

In case of an uniform linear array, to increase directivity it is necessary to increase array length. But due to this, the secondary or minor lobes are observed in the overall pattern. In some practical application, it is needed to have a pattern with single main lobe with no minor lobes. So in such cases binomial array is preferred. The binomial array with spacing between two adjacent elements equal to or less λ/2 than produces a pattern without side lobes.

Basically a binomial array is **non uniform amplitude array**. The amplitudes of the elements in the binomial array are arranged such that there are no side lobes in the resultant.

## Two element array

Let us consider that an array consists two identical sources with equal in-phase excitation with distance d between two elements as shown in the Fig. (a)




**(a) Two element array with spacing d (b) radiation pattern for d = λ/2**

For above array, the normalized electric field pattern is given by

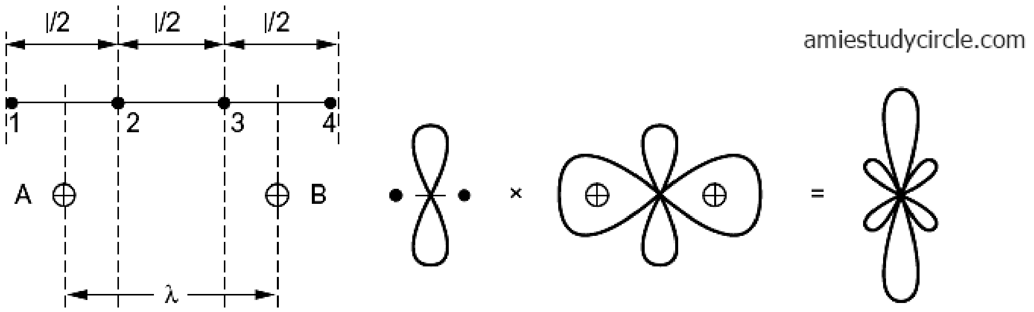
$$E_n = \cos\left[\frac{\pi d}{\lambda}\cos\theta\right]$$

So with d = λ/2, it is observed that the pattern has no side lobes and it is figure eight (8) shape pattern as shown in the Fig. (b).

$$\therefore \qquad E_n = \cos\left[\frac{\pi(\lambda/2)}{\lambda}\cos\theta\right] = \cos\left[\frac{\pi}{2}\cos\theta\right]$$

## Four element array

Now suppose to increase directivity, array length is increased. So let us now consider that instead of two elements, an array consists 4 elements spaced λ/2 apart as shown in the Fig. (a). Note that A and B (represented by ⊕) represent each a group of two elements separated by distance λ/2 These two groups are separated by distance λ.

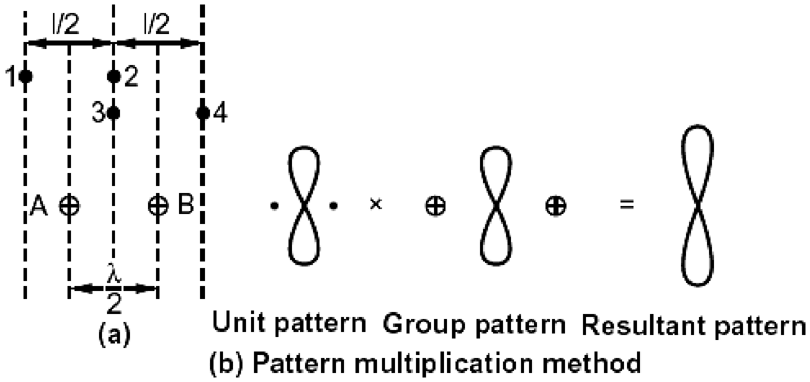




(a) 4 - element array (b) Unit pattern (c) Group pattern (d) Resultant pattern

So the unit pattern of elements with separation λ/2 is figure eight shape as shown in the Fig. (b) while the group pattern with separation A is as shown in the Fig. (c). So by pattern multiplication method, the resultant pattern is as shown in the Fig. (d). Note that the resultant pattern has side lobes.

To reduce or eliminate completely we should have group pattern also of figure eight pattern which is possible only when the separation between the group elements is less than or equal to λ/2 so that pattern is figure of eight pattern. To achieve this let us move group B towards group A i.e. elements 3 and 4 towards elements 1 and 2 till distance of separation is λ/2. When group B is at a distance λ/2 from A, we observe that elements 2 and 3 are overlapping or coinciding as shown in the following figure (a).




Now as the two groups A and B are also separated by distance λ/2 the group pattern is figure eight pattern. Thus the resultant pattern is figure eight squared pattern as it is a product of two figure eight pattern.

For four elements array, the resultant electric field is given by

$$(E_R)_n = (E_n)_{unit\ pattern}\, x (E_n)_{group\ pattern}$$

$$= \cos\left[\frac{\pi}{2}\cos\theta\right] x \cos\left[\frac{\pi}{2}\cos\theta\right] = \cos^2\left[\frac{\pi}{2}\cos\theta\right]$$

## ARRAY FACTOR

The array factor is the| ratio of the magnitude of the resultant field to the magnitude of the maximum field.

$\therefore$ $$AF = \frac{|E_T|}{|E_{max}|}$$

But maximum field is $E_{max} = 2E_0$.

$\therefore$ $$AF = \frac{|E_T|}{|2E_0|} = \cos\left(\pi.\frac{d}{2}\cos\phi\right)$$

The array factor represents the relative value of the field as a function of ϕ. It defines the radiation pattern in a plane containing the line of the array.

## IMPEDANCE MATCHING IN ANTENNA

Impedance matching in antennas can be done by

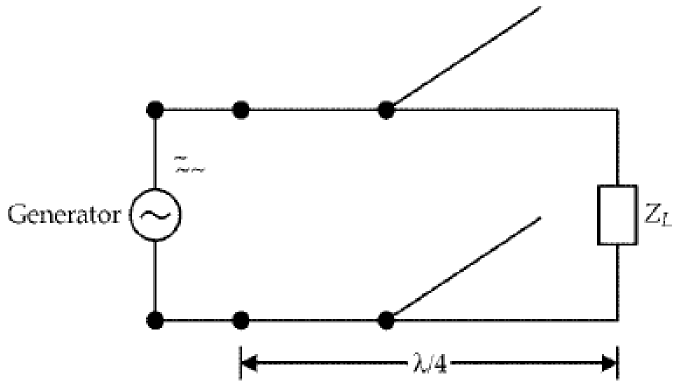
- stubs

- folded dipoles
- balum

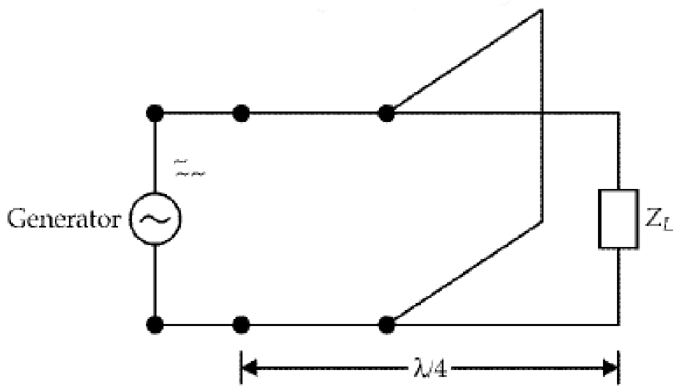
**Stubs**

A stub is a piece of transmission line one end of which is connected to the transmission line for matching with the load impedance. Its purpose is to tune out the reactance. The second end of the stub can be open circuited or short circuited. Short circuited stub lines are usually used to avoid radiation losses.

The method of stub matching of a pair of transmission lines is shown in following figure.

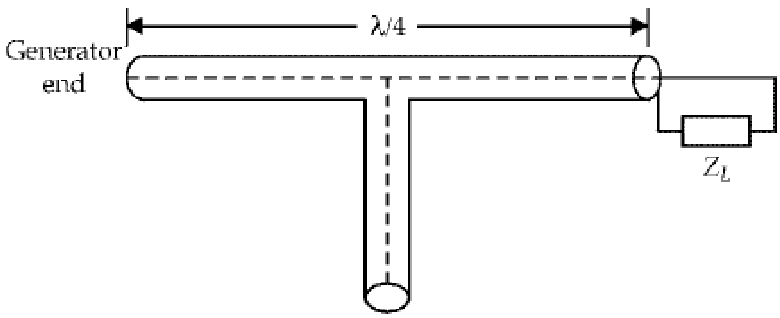



Matching with open stub

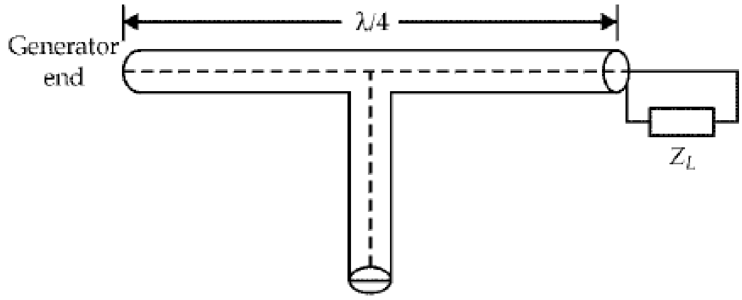



**Matching with shorted stub**

The matching of a coaxial line is shown in following figure.



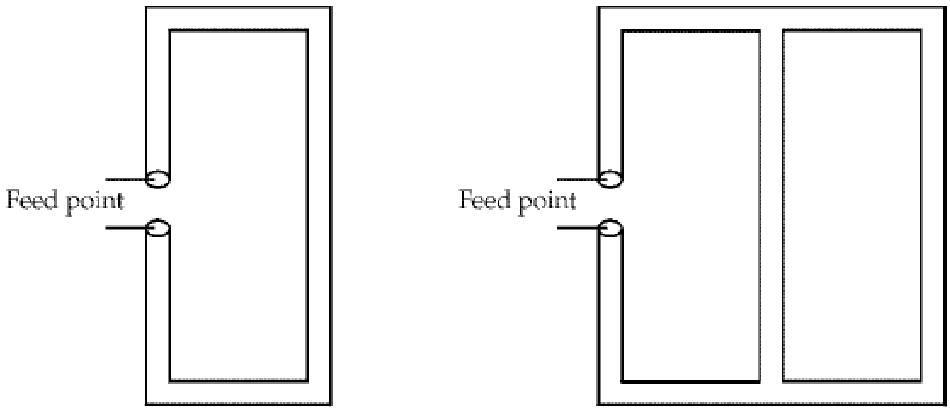

**Open stub matching**




**Shorted stub matching**

## Folded dipoles

These are used to increase the impedance. Typical folded dipoles are shown in following figure.




**(a) Dipole with single fold (b) Dipole with double fold**

## Balun

The word is derived from **BALanced to UNbalanced**. A dipole is a balanced load. In a dipole, the two arms have equal currents. The impedance of arms to ground should be the same.

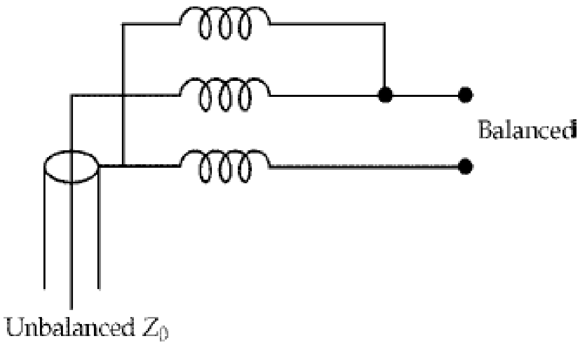
A **balun** is a balanced to unbalanced transformer It is a circuit element. It is usually connected between a balanced line and an unbalanced line or an antenna. As a coaxial line is unbalanced, a balun is connected between a coaxial line and a dipole. Transmission lines are used as baluns at high frequencies and centre tapped transformers are used as baluns at lower frequencies. The primary is unbalanced. Centre tapped secondary winding is balanced and is connected to the antenna.

Baluns are of two types:

- Broadband
- Narrowband

**Broadband**

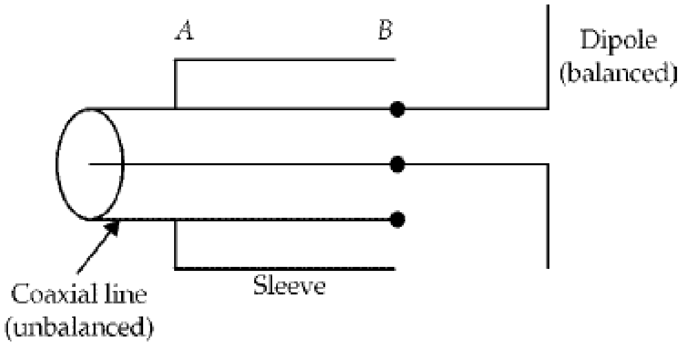
An example is the conventional transformer. See given figure.




In this figure, a coaxial cable of 75 W or 50 W is used to feed a dipole. Its impedance transfer ratio is 1:1.

**Narrowband Balun**

An example is bazooka or sleeve or choke. A dipole is connected to the inner conductor of a coaxial line with a sleeve around it (see figure).



# ASSIGNMENT

**Q.1. (AMIE S17, 10 marks):** What do you mean by array antenna? Compare the Yagi Uda and log periodic antenna.

**Q.2. (AMIE S17, 10 marks):** What do you mean by antenna arrays? Discuss different types of linear antenna arrays and explain binomial array.

**Q.3. (AMIE W18, 10 marks):** Explain the concept of antenna array. Also find the expression for array factor.

**Q.4. (AMIE W16, 4 marks):** Define array factor and element factor.

**Q.5. (AMIE S20, 10 marks):** Explain the principle of binomial array in detail.

**Q.6. (AMIE W15, 17, S16, 6 marks):** Describe briefly binomial amplitude distribution. Draw the radiation pattern of four element array using binomial distribution.

**Q.7. (AMIE W18, 10 marks):** Do comparative analysis between broadside antenna array and end fire antenna array.

**Q.8. (AMIE S19, 20, W19, 10 marks):** Describe the broadside array and end fire array.

**Q.9. (AMIE W17, 19, S19, 4 marks):** What is the importance of pattern multiplication? Write its advantages and advantages.

**Q.10. (AMIE S15, 6 marks):** Explain different methods to excite the antenna.

**Q.11. (AMIE W18, 10 marks):** What factors govern the selection of the feed point of a dipole antenna? How do current feed and voltage feed differ? Draw the circuits of two typical antenna couplers and briefly explain their operation.

**Q.12. (AMIE S15, 16, W15, 17, 8 marks):** Discuss different impedance matching techniques for an antenna with an appropriate diagram.

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